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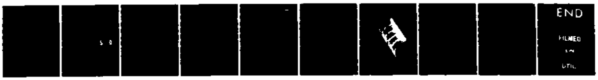

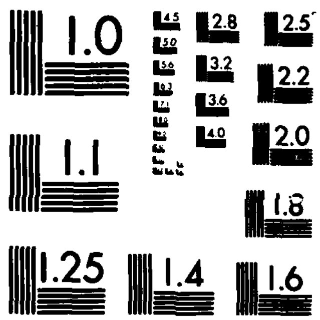
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AD-A164 272

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER No. 19	2. GOVT ACCESSION NO. AD-A164 272	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Transport Properties of Relativistic Electron Beams Through Linearly Polarized Magnetic Wigglers.		5. TYPE OF REPORT & PERIOD COVERED Technical Report 10/01/82 - 09/30/83
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Luis R. Elias and James Hu		8. CONTRACT OR GRANT NUMBER(s) N00014-80-C-0308
9. PERFORMING ORGANIZATION NAME AND ADDRESS University of California Quantum Institute Santa Barbara, CA 93106		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 61153N; RR011-07-06; NR603-001
11. CONTROLLING OFFICE NAME AND ADDRESS ONR 1030 E. Green St. Pasadena, CA 91106		12. REPORT DATE 1983
		13. NUMBER OF PAGES
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified/Unlimited
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from

18. SUPPLEMENTARY NOTES

Proceedings of the International Conference of Lasers '82, 154, 1983.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Properties, Electron, Polarized, Wigglers.

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

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Transport Properties of Relativistic Electron Beams Through Linearly Polarized Magnetic Wigglers

Ren-Chau J. Hu and Luis Elias

Lasers 82

QIFEL019/82

TRANSPORT PROPERTIES OF RELATIVISITIC ELECTRON BEAMS
THROUGH LINEARLY POLARIZED MAGNETIC WIGGLERS

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Abstract

When a relativistic electron beam moves through a linearly polarized magnetic wiggler it exhibits betatron oscillations along the direction perpendicular to the motion. There is also a small defocusing effect along the transverse direction because of space charge repulsion. In our case with a low emittance electron beam, computer simulation shows a negligible increase in emittance, although the phase space in the transverse plane may vary greatly from period to period because of the betatron effect.

Introduction

An important feature of the UCSB FEL is its electron beam recirculation. Because of this recirculation, the electron beam transport properties of the wiggler are extremely important even if we ignore their effect on the gain mechanism. The parameters of the wiggler and the electron beam in our simulation are shown in Tabel 1 and Fig. 1.

Table 1 Wiggler and Electron Beam

WIGGLER		ELECTRON BEAM	
Period	3.6 cm	Energy	3 Mev
Peak Field	416 Gauss	Current	2 Amp
Number of Periods	160	Radius	2.5 mm
Length	576 cm	Emittance	1 mm-mr

Magnetic Field

$B_y(x,0,z)$ is calculated by applying the Biot-Savart Law to an equivalent current sheet model of the magnet array, with this and the Laplace equation for the scalar potential we can find the coefficients of the expansion of the field along the z-axis. The form of this wiggler field is

$$B_x^w = f(x,y)\,\mathrm{SIN}kz \quad , \qquad (1a)$$

$$B_y^w = B_o[1+g(x,y)]\,\mathrm{COSH}ky\,\mathrm{SIN}kz \quad , \qquad (1b)$$

$$B_z^w = B_o[1+h(x,y)]\,\mathrm{SINH}ky\,\mathrm{COS}kz \quad , \qquad (1c)$$

where $k = 2\pi/\lambda$, λ is the period of the wiggler. The functions $f(x,y)$, $g(x,y)$ and $h(x,y)$ are due to the finite size of the magnets and would vanish if the magnets were infinitely long. In our model, we calculate the field to fourth order in the expansion of powers of x and y along the z-axis. We take B_o = 416.2 Gauss.

Trajectories

From the Lorentz force equation we get the equations of the electron trajectories:

$$x'' = e/p\,\sqrt{1+x'^2+y'^2}\,[y'B_z - (1+x'^2)B_y + x'y'B_x] + \gamma m e/p^2\,(1+x'^2+y'^2)(E_x - x'E_z) \quad , \qquad (2a)$$

$$y'' = -e/p\,\sqrt{1+x'^2+y'^2}\,[x'B_z - (1+y'^2)B_x + x'y'B_y] + \gamma m e/p^2\,(1+x'^2+y'^2)(E_y - y'E_z) \quad , \qquad (2b)$$

where all the derivatives are taken with respect to z, i.e., $x' = dx/dz$, $y' = dy/dz$, etc. Both wiggler fields and space charge fields are included in these equations.

To find some basic features of the beam we can simplify these equations by keeping only the lowest order terms, giving

[redacted]

$$x'' = -e/p \cdot By = -e/p \cdot Bo\,\mathrm{SIN}kz\ , \tag{3}$$

$$x' = e/p/k \cdot Bo\,\mathrm{COS}kz\ , \tag{4}$$

$$y'' = -e/p \cdot x'Bz = -e^2/p^2/k \cdot Bo^2\,ky\,\mathrm{COS}kz = -e^2/p^2\,Bo^2\,\mathrm{COS}kz \cdot y\ . \tag{5}$$

The focusing constant $Q = \langle e^2/p^2 Bo^2 \cos kz \rangle^{\frac{1}{2}} = (e^2/p^2/2 \cdot Bo^2)^{\frac{1}{2}} = 2.57/m.$ (6)

From Eqns. 5 and 6 we see the presence of a betatron oscillation along the main field direction, i.e., the y-direction. The envelope of the electron beam is shown in Fig. 2 where both the betatron effect and the space charge effect are clearly demonstrated. Notice that we inject the electrons with some focusing slope in order to form a beam waist at about the midpoint of the path. The result also shows that the betatron effect is exactly the same as predicted by Eqn. 6, i.e., $Q = 2\pi/\lambda_B = 2.57/m$ implies that $\lambda_B = 2\pi/2.57\ m = 2.44\ m = 58\ \lambda$, where λ_B is the wavelength of the betatron oscillation. For a total path of 160 λ we should be able to see about 2.4 periods of betatron oscillation or 4.8 peaks.

Phase space

The transverse phase space is also studied and shown in Fig. 3. Besides the betatron effect we find that both the y-phase space and the x-phase space are always correlated, though there are some aberations in the x-phase space. These aberations are such that some electrons get larger x-slopes after about 10 periods and come back after another 10 periods and have the same phase space again. To explain this, we solve the equation of motion in the x-direction to the lowest order:

$$\Delta x' = x'(z_2) - x'(z_1) = -e/p \int_{z_1}^{z_2} B_y^w\, dz \tag{7}$$

The change of the x-slope is equal to the integral of B_y^w along the path. If B_y^w is a perfect sinusoidal function, which is true only in the x-z plane (y=0), the slope of the electrons will not change at all after each period. For those off-plane electrons, the y-position, and hence the amplitude of B_y^w, changes because of the betatron oscillation (see Fig. 2). The electrons are picking up slopes while they are sliding down to the valley of the envelope and losing slopes while climing up. With a suitable choice of the peak wiggler field the electron beam can again become not aberated at the end of the wiggler so that we can collect most of the electrons.

In real cases the wiggler is not perfect. The field of each period is not identical. There are always some fluctuations in the amplitude. Will they affect the correlation of the electron beam? To answer this question we make another simulation with an assumption that there is a 5% fluctuation in the field of the wiggler. The result is shown in Fig. 4. We see that the electron beam can still be somewhere without aberated along the path. The reason for this well behaved phenomenon is the same as above except that the fluctuations in the field do not contribute greatly to the emittance because the average change of the slope due to the fluctuations of the field is close to zero.

Conclusions

The emittance of an electron beam of initially low emittance will not change greatly during passage through a linearly polarized magnetic wiggler. Thus the wiggler will not adversely effect the recirculation of the electron beam. By choosing a correct peak wiggler field we should be able to eliminate the emittance of the electron beam at the end of the wiggler.

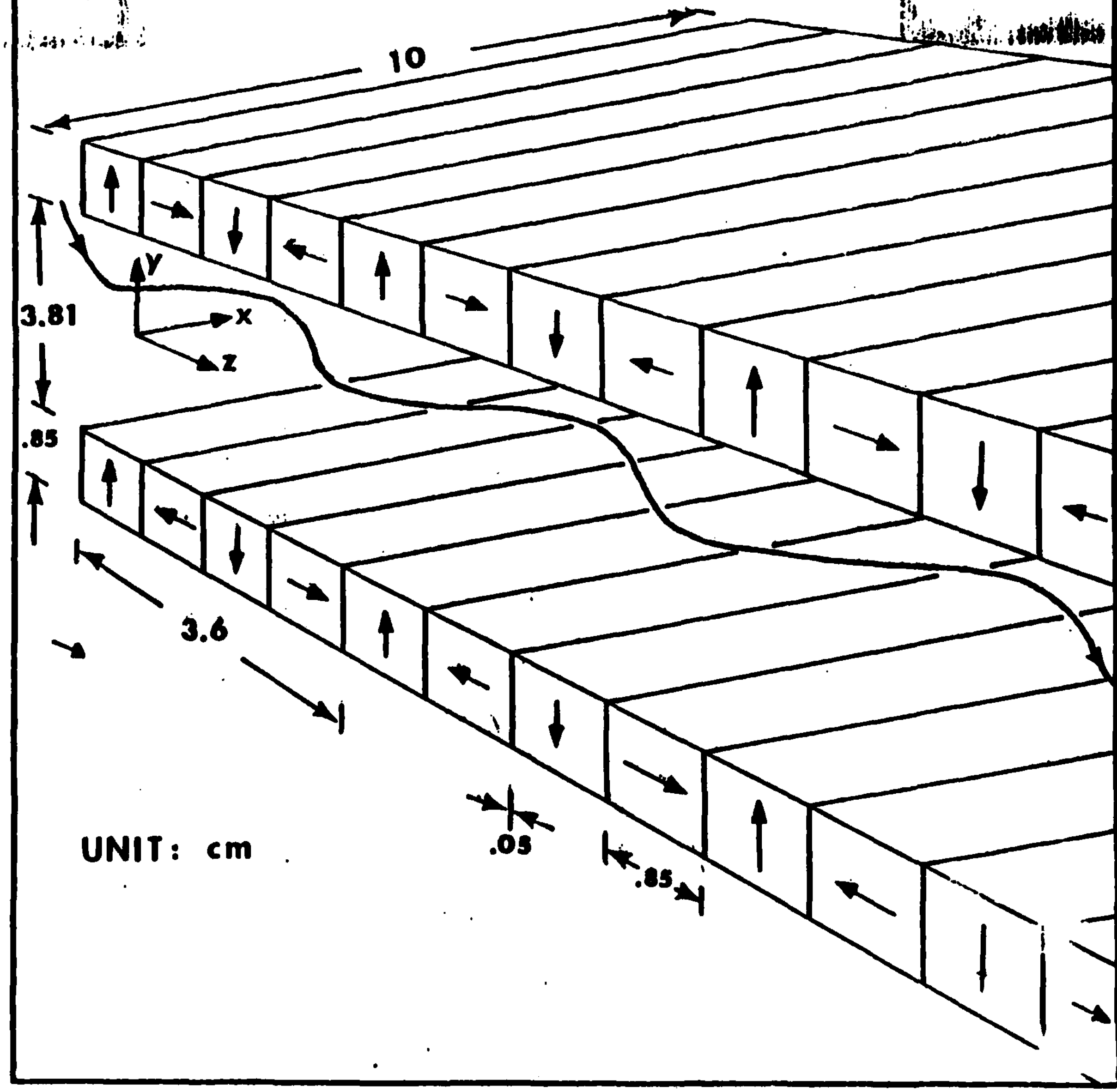

Figure 1 The Wigglers and the Trajectory

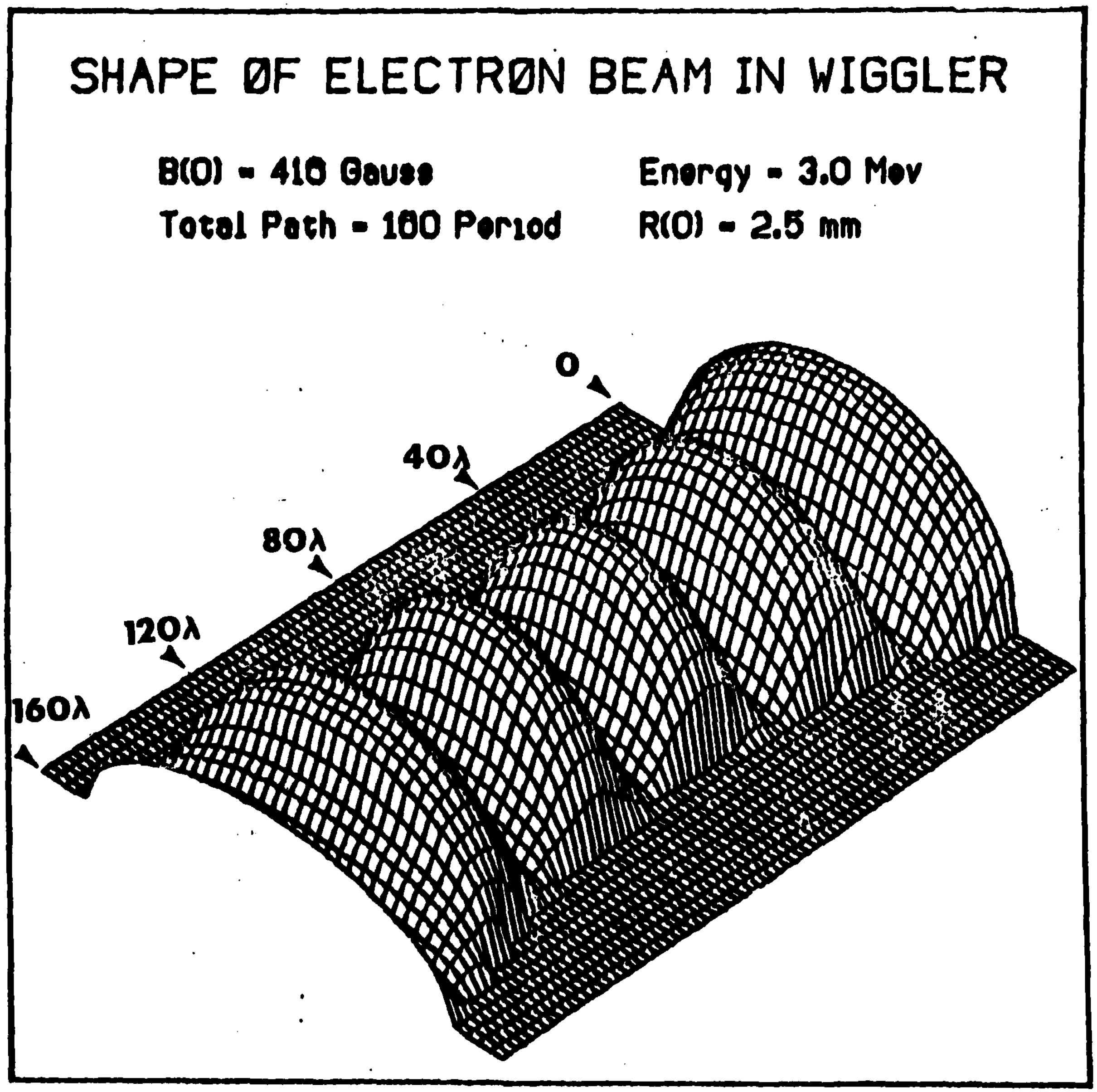

Figure 2 Envelope of the Electron Beam

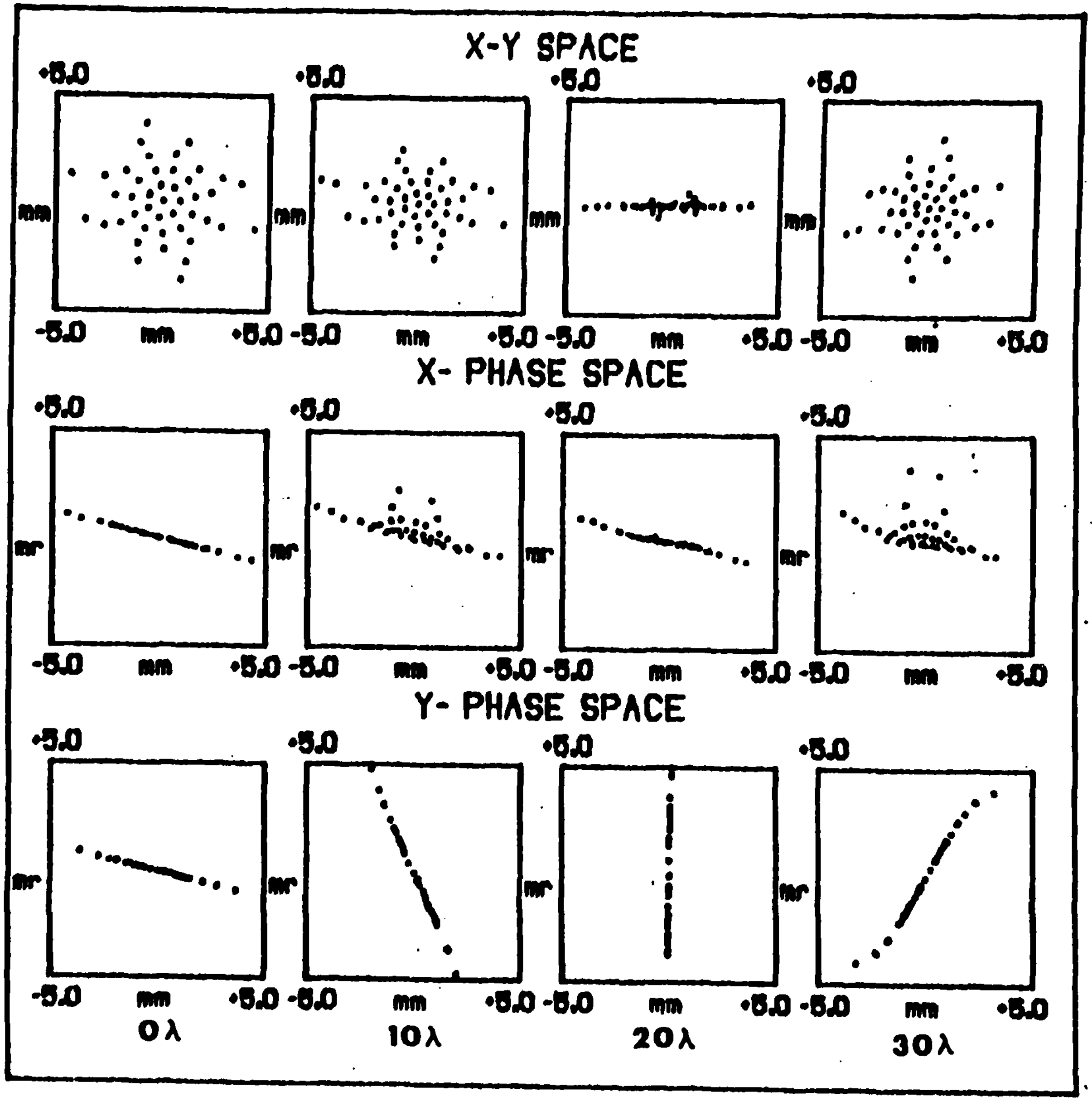

Figure 3 Phase Space — through perfect wigglers

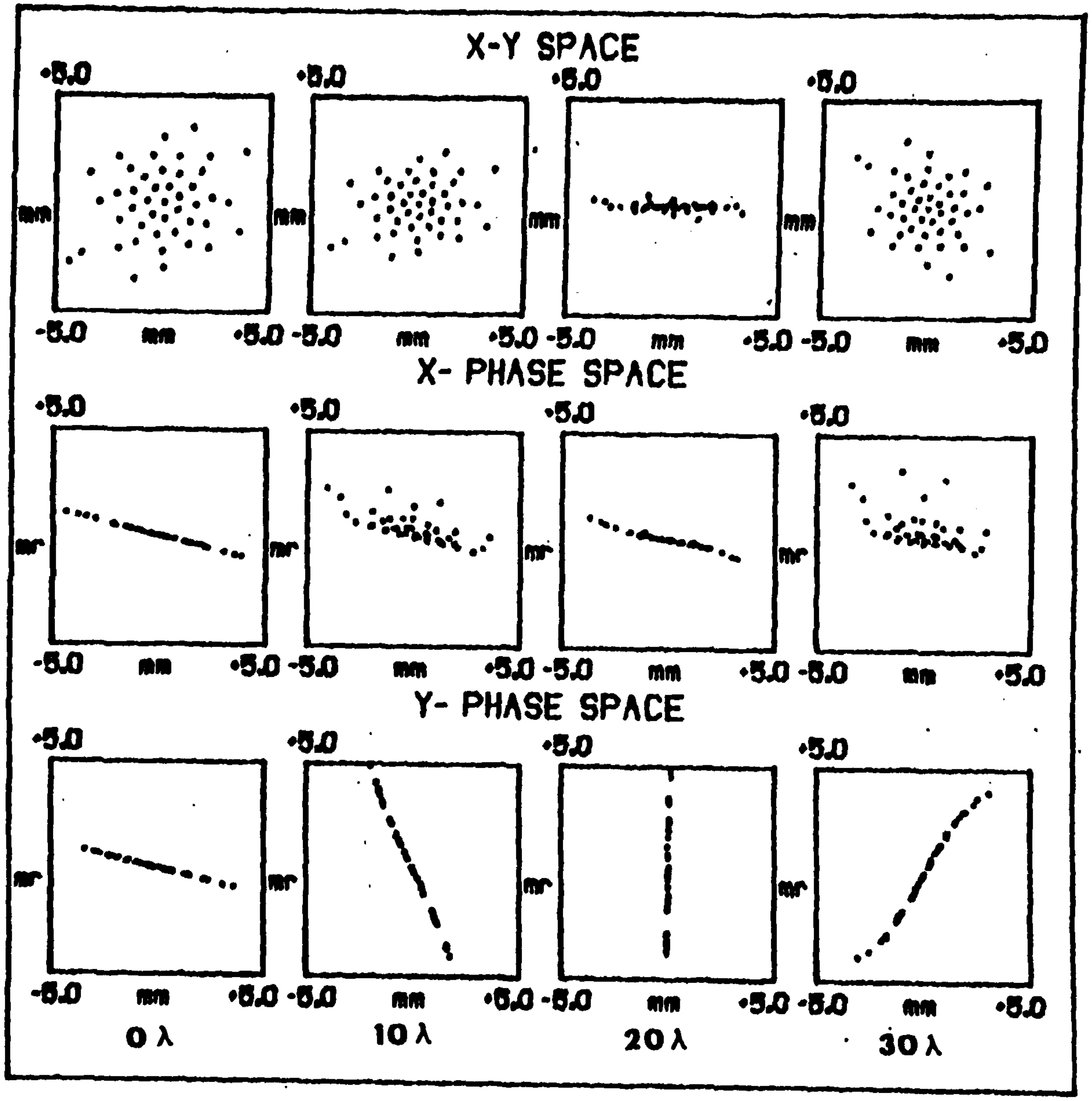

Figure 4 Phase Space — through 5% deviated wigglers

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